# Seismic estimation of a stone lantern using 3-D DEM analysis and shaking table test

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# Seismic estimation of a stone lantern using 3-D DEM analysis and shaking table test

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## Introduction

A stone construction like a lantern and a gravestone is a simple unstable structure which stacked stones. So the damage of a stone lantern caused by the earthquake has occurred mostly. It is necessary to take the prevention from a fall of a lantern into consideration because the fall of a lantern is very dangerous.



## Introduction

Seismic Estimation of the stone lantern is not evaluated in Japan.

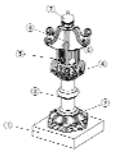

The effect of reinforcement will not be enough and a lantern will fall.

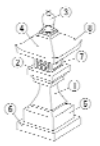
In this study, we estimate the seismic performance of a stone lantern using 3-D DEM analysis and real scale shaking table test, and evaluate the seismic resistance of the reinforced lantern.

## Shaking Table Test using Real Scale Lantern

## Shaking Table Test

Type of Stone Lanterns
Slender Type (Kasuga Tourou)
Top-Heavy Type (Shinzen Tourou)

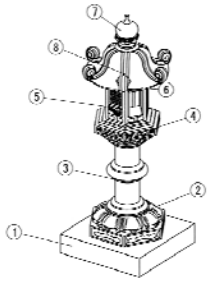

Kasuga Tourou


Shinzen Tourou

## Shaking Table Test

Cases
Non-Reinforcement Lantern
Reinforcement Lantern
(Inner-Steel Pipe Penetrated)

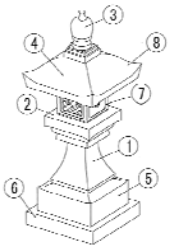

## Parameter of Kasuga Tourou



| | |
|---|---|
| Height (mm) | 1,870 |
| Weight (N) | 5,723.2 |

| | | Size (mm) | | |
|---|---|---|---|---|
| | | Width | Length | Height |
| ① | Shiba-Dai | 700 | 700 | 150 |
| ② | Daiza | 600 | 520 | 180 |
| ③ | Hashira | 300 | 300 | 580 |
| ④ | Hibukuro-Uke | 520 | 450 | 160 |
| ⑤ | Hibukuro | 340 | 294 | 320 |
| ⑥ | Itaishi | 320 | 277 | 180 |
| ⑦ | Giboshi | 180 | 180 | 250 |
| ⑧ | Kasa | 700 | 619 | 230 |

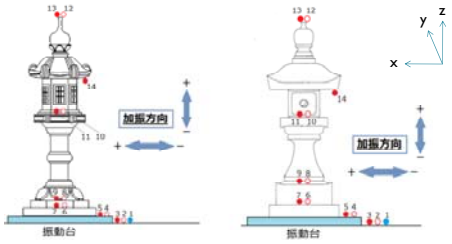
## Parameter of Shinzen Tourou



| | |
|---|---|
| Height (mm) | 1,800 |
| Weight (N) | 6,752.2 |

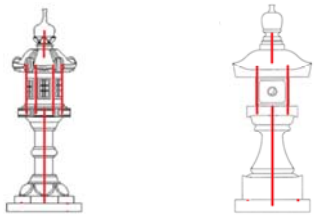
| | | Size (mm) | | |
|---|---|---|---|---|
| | | Width | Length | Height |
| ① | Hashira | 374 | 374 | 439 |
| ② | Hibukuro-Uke | 439 | 439 | 163 |
| ③ | Giboshi | 179 | 179 | 309 |
| ④ | Itaishi | 293 | 293 | 154 |
| ⑤ | Naka-Dai | 520 | 520 | 228 |
| ⑥ | Shiba-Dai | 660 | 660 | 205 |
| ⑦ | Hibukuro | 293 | 293 | 260 |
| ⑧ | Kasa | 683 | 683 | 325 |

## Measurement of Specimen




| | |
|---|---|
| ○ | x方向 |
| ● | y方向 |
| ● | z方向 |

## Reinforcement Lantern



Kasuga Tourou　　Shinzen Tourou

Strength of Stone and Reinforcement Equipments

N/cm$^2$

| | 圧縮 | 引張、曲げ |
|---|---|---|
| 石材：御影石 | 6000 | 640 |
| ボルト：SUS304 | 23500 | 23500 |
| 鉄筋：SD295A | 29500 | 29500 |

## Shaking Table Test

Earthquake Motions

Sine Wave・・ Kasuga Tourou : 1.5Hz and 9.0Hz(100~400gal)

Shinzen Tourou : 4.0Hz and 7.5Hz(100~400gal)

Type of Earthquake Motions

JMA-Kobe (NS and UD)

(1995 Hyogoken Nambu Earthquake)

K-NET Ichinoseki (NS and UD)

(2008 Iwate-Miyagi Internal Earthquake)

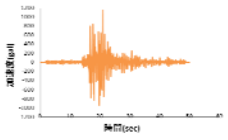
## Shaking Table Test (Earthquake Motions)

1995 Hyogoken Nambu Earthquake

<NS Component>

Max Acc. : 1,152gal

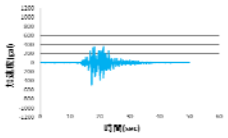
Mac Vel. : 102kine



< UD Component >

Max Acc. : 357gal

Mac Vel. : 36kine



## Shaking Table Test (Earthquake Motions)

2008 Iwate-Miyagi Internal Earthquake

<NS Component>

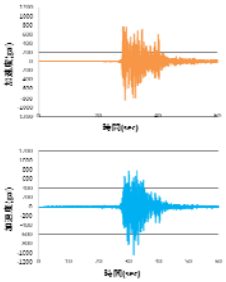
Max Acc. : 833gal

Mac Vel. : 54kine

< UD Component >

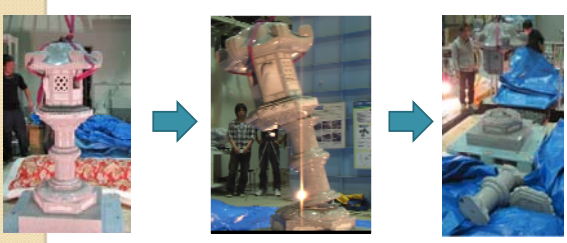
Max Acc. : 1,032gal

Mac Vel. : 38kine



## Test Result(Kasuga: Non-reinforcement)

JMA-Kobe (50%) : Felt down with rocking, rotation and sliding



Before Test　Shaking　After Test

## Test Result(shinzen: Non-reinforcement)

JMA-Kobe (50%) : Rocking and rotating occured at column, but specimen did not fall down.

Before Test　Shaking　After Test

## Test Result(shinzen: Non-reinforcement)

JMA-Kobe (70%) : Felt down with rocking and sliding except rotating.

Before Test　Shaking　After Test

## Test Result (Kasuga: Reinforcement)

JMA-Kobe : Rocking and rotating occured a little at Hibukuro-uke, but specimen did not fall down.

Ichinoseki : Severe rocking occured at Hibukuro-uke. Specimen did not fall down but minor damaged and cracked at a column.

## Test Result (Shinzen: Reinforcement)

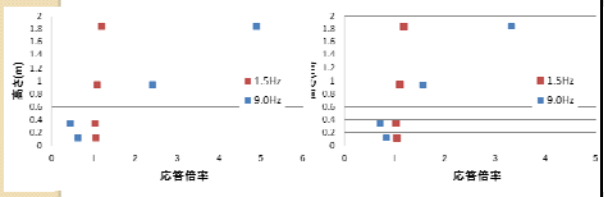
神戸波 : Rocking and rotating occured a little at Hibukuro-uke, but specimen did not fall down.

一関波 : Severe rocking occured at Hibukuro-uke. Specimen did not fall down.

## Test Result (Kasuga: Reinforcement)

Sine Wave NS Component

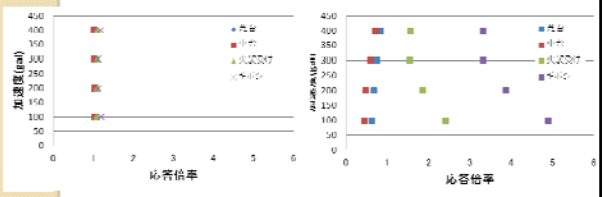
100gal 400gal




## Test Result (Kasuga: Reinforcement)

Sine Wave NS Component

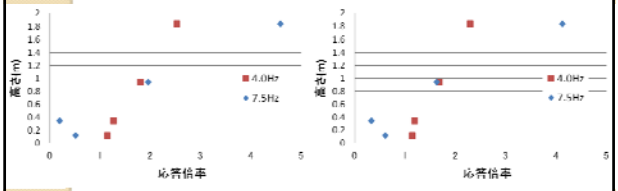
1.5Hz 9.0Hz




## Test Result (Shinzen: Reinforcement)

Sine Wave NS Component

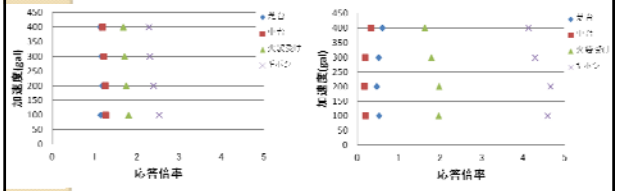
100gal 400gal



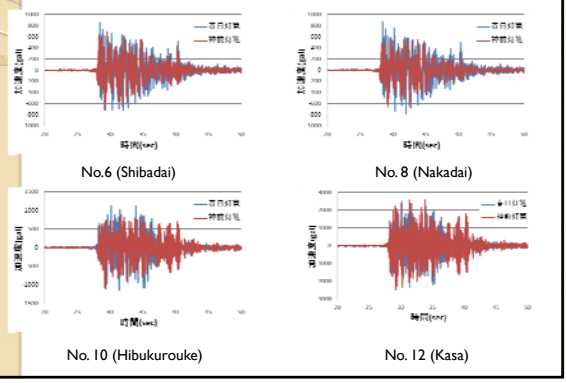

## Test Result (Shinzen: Reinforcement)

Sine Wave NS Component

4.0Hz 7.5Hz



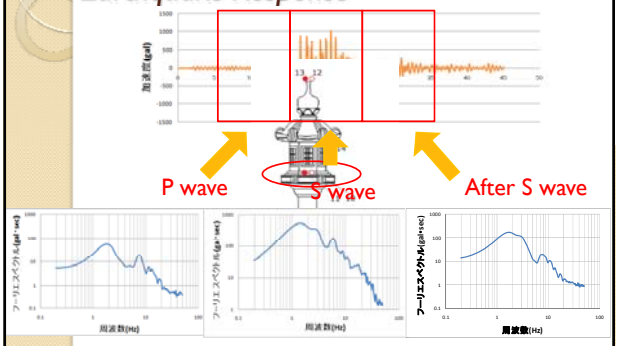

## Test Result (Earthquake Motions)



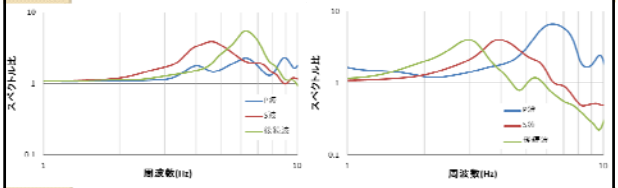
No.6 (Shibadai) No. 8 (Nakadai)

No. 10 (Hibukurouke) No. 12 (Kasa)

## Spectral Characteristics of Earthquake Response



## Test Result (Kasuga: Reinforcement)



Transfer Function
(JMA-Kobe: NS Component)

Transfer Function
(K-NET Ichinoseki: NS Component)

## Test Result (Shinzen: Reinforcement)

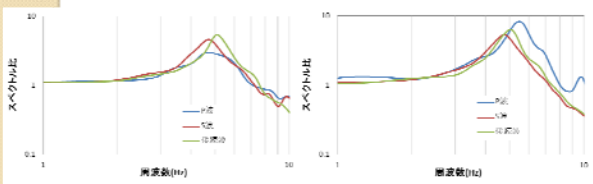


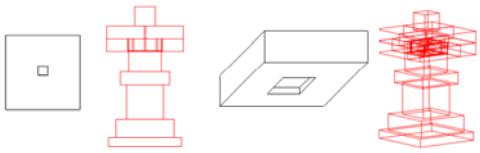
図　神戸波の伝達関数 NS方向

図　一関波の伝達関数 NS方向

## *Earthquake Response Analysis Using 3-D DEM*

## Analytical Model

In order to create a simple model, a component is expressed in a rectangular parallelepiped. The part which is carrying out form with the complicated hole which inserts an axis is expressed by combination of two or more rectangular parallelepipeds.

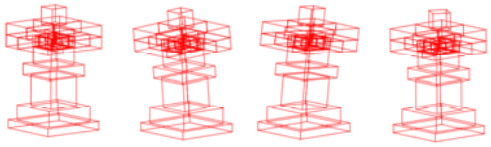


2D View　　3D View

Model of Shinzen-Tourou

## Analytical Results

Non-Reinforcement : JMA-Kobe(50%)



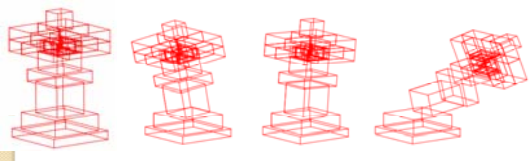
16s　17s　18s　19s

Experiment：Rocking and rotating occured at column, but specimen did not fall down.

Analysis：Rocking occured at column, but specimen did not fall down.

## Analytical Results

Non-Reinforcement : JMA-Kobe(70%)



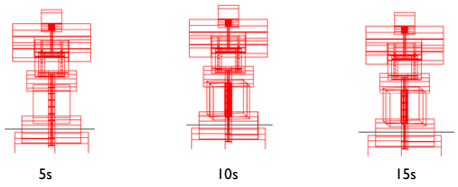
16s　17s　18s　19s

Experiment：Felt down with rocking and sliding except rotating.

Analysis：Same result as a experiment and direction of falling down is also same.

## Analytical Results

Reinforcement : K-NET Ichinoseki



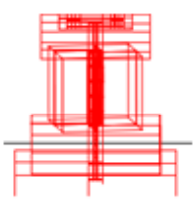
5s　　10s　　15s

Experiment：Minor rocking and rotating occured at column, but specimen did not fall down.

Analysis：Same result as a experiment and direction of rotation is also same.

## Analytical Results

Reinforcement : K-NET Ichinoseki

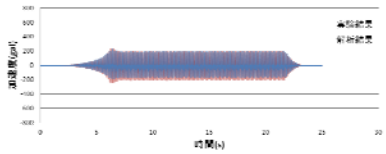


Experiment：Minor rocking and rotating occured at column, but specimen did not fall down.

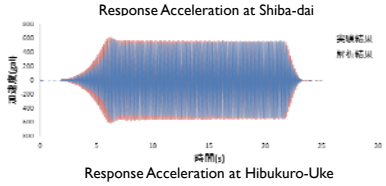
Analysis：Same result as a experiment and direction of rotation is also same.

## Analytical Results

Sine Wave 7.5Hz NS Component



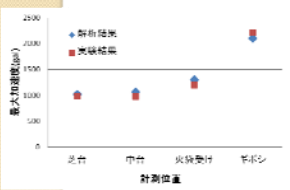
Response Acceleration at Shiba-dai



Response Acceleration at Hibukuro-Uke

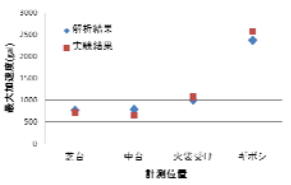
## Analytical Results

| | Response Acceleration(gal) | |
|---|---|---|
| | Experiment | Analysis |
| Shiba-Dai | 1,014 | 975 |
| Naka-Dai | 1,064 | 970 |
| Hibukuro-Uke | 1,300 | 1,195 |
| Giboshi | 2,102 | 2,205 |



Maximum Acceleration of JMA-Kobe

| | Response Acceleration(gal) | |
|---|---|---|
| | Experiment | Analysis |
| Shiba-Dai | 762 | 721 |
| Naka-Dai | 788 | 648 |
| Hibukuro-Uke | 998 | 1,075 |
| Giboshi | 2,373 | 2,574 |



Maximum Acceleration of K-NET Ichinoseki

## Remarks

1. Non-reinforce lanterns cannot prevent falling down even in 50% revel JMA-Kobe Earthquake. It is required to reinforce a lantern.
2. This reinforce method which let axis pass in a specimen have effect sufficiently. But some cracks and breaks is verified at Kasuga-Tourou.
3. This reinforce method cannot effect prevention of rocking sufficiently.
4. Natural frequency of lanterns are about 5Hz.
5. Natural frequency of lanterns become fall because of rocking.
6. The frequency characteristic changes with a kind of earthquake motion in Kasuga-Tourou.

## Thank you!
## 謝謝！